Testosterone administration increases social discounting in healthy males

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Abstract: Although testosterone is thought to induce antisocial and aggressive behavior, research on social economic interactions has associated it with prosocial and affiliative behavior. Here, we investigated the effects of testosterone on social distance-dependent generosity in an economic discounting task where participants chose between selfish and generous alternatives. We administered testosterone gel or placebo to men in a double-blind, randomized design and measured how willing they were to share rewards with close and distant others. Across two studies (total n = 174), testosterone administration consistently increased social discounting, that is participants became more selfish, particularly with regard to distant others (vs. close others). This effect was not explained by testosterone-induced increases in social distance perception. Our findings provide causal evidence that-testosterone reduces generosity in human economic decision-making. Moreover, they suggest that the valuation and the perception of social distance are independently affected by testosterone.

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Study 1: Saliva sampling and endocrine assays

We collected three saliva samples for each participant to determine levels of testosterone and androstenedione (i.e., upstream metabolite of testosterone), one before gel administration (T0) and the other two samples three hours (T1) and four hours (T2) after gel administration. Saliva samples were collected using passive drool. Samples were frozen immediately following collection and held at −80° until they were assayed.

Samples were assayed in a 3200 QRTAP high-performance liquid chromatography tandem mass spectrometer (ABI, USA) equipped with atmospheric pressure chemical ionization sources (LC-APCI-MS/MS). Testosterone was measured in positive mode as described by Gao and colleagues (2013). The lower limit of quantification (LOQ) was 0.012 ng/ml for salivary testosterone and 0.009 ng/ml for salivary androstenedione. For testosterone, the intra-assay coefficients were 10.4% at 0.1 ng/ml, 12.7% at 0.2 ng/ml, 14.1% at 10 ng/ml, 5.2% at 20 ng/ml, and 5.6% at 100 ng/ml. Inter-assay coefficients were 13.8% at 0.1 ng/ml, 11.4% at 0.2 ng/ml, 12.1% at 10 ng/ml, 6.4% at 20 ng/ml, 5.6% at 100 ng/ml, and recovery ranged between 90.0% and 112.1% at the five concentrations. For androstenedione, the intra-assay coefficients were 12.0% at 0.1 ng/ml, 11.8% at 0.2 ng/ml, 6.5% at 10 ng/ml, 11.9% at 20 ng/ml, and 12.5% at 100 ng/ml. Inter-assay coefficients were 12.8% at 0.1 ng/ml, 12.3% at 0.2 ng/ml, 9.9% at 10 ng/ml, 12.9% at 20 ng/ml, 13.5% at 100 ng/ml, and recovery ranged between 95.2% and 105.7% at the five concentrations.

Data analysis

To determine whether testosterone/androstenedione increased more in the testosterone group than in the placebo group, we performed a linear mixed effects analysis on the salivary testosterone levels. Treatment (testosterone vs. placebo) served as a fixed effect factor, time point as a continuous fixed-effect predictor, and participant as a random-effect factor. We log-transformed all hormonal levels.

Testosterone levels

As a manipulation check, we first asked whether testosterone increased more in the testosterone than

the placebo group. The two main effects of treatment and time point were significant, $\chi^2(1) = 62.56$, $p < .001$, and $\chi^2(2) = 70.71$, $p < .001$, respectively. Importantly, the interaction between treatment and time was also significant, $\chi^2(2) = 75.92$, $p < .001$. Simple effect analysis showed that testosterone levels did not differ between the testosterone and the placebo group at T0 ($p > .05$), but were significantly elevated 3 h (T1; $b = 3.51$, SE = 0.35, t = 10.05, $p < .001$), and 4 h (T2; $b = 3.95$, SE = 0.30, $t = 13.20$, $p < .001$) after administration in the testosterone group compared to the placebo group. Thus, as expected, testosterone levels increased more around the time of behavioral testing in the testosterone than in the placebo group (see Fig. S1).

We noticed that the testosterone levels in the placebo group and baseline testosterone level (T0) in the testosterone group were higher than expected in normal young men (greater than 400 pg/mL). Previous research suggested that such unusually high measurements are likely caused by local spreading of testosterone into saliva tubes, but physiological levels were unaffected by superficial contact with the dry testosterone gel (Genzen et al., 2018; Nave et al., 2018, 2017). This was confirmed by analyzing the upstream metabolite of testosterone, androstenedione, which remained at normal levels in both the placebo group and at T0 in the testosterone group (see below).

Androstenedione levels

The two main effects of treatment and time points were significant, $\chi^2(1) = 55.76$, $p < .001$, and $\chi^2(2) = 62.41$, $p < .001$, respectively. Treatment interacted significantly with time, $\chi^2(2) = 71.57$, $p < .001$. Further analysis revealed that androstenedione levels did not differ at T0 ($p > .05$) but were significantly increased 3 h (T1; $b = 2.02$, SE = 0.22, t = 9.28, $p < .001$) and 4 h (T2; $b = 2.33$, SE = 0.24, t = 9.69, $p < .001$) after administration in the testosterone compared to the placebo group (see Fig. S2.). Note that the baseline level (T0) of androstenedione was at normal level in all participants, and none of the placebo group participants exhibited unusually high values of androstenedione after testosterone administration (at T1 and T2). Thus, the unusually high testosterone values were very likely due to the local spreading of testosterone into saliva tubes. More studies are needed to directly test this hypothesis (Genzen et al., 2018).

Correlation between baseline testosterone/androstenedione levels and behavior

Baseline testosterone and androstenedione levels were log-transformed before data analysis and were highly correlated, $r = 0.534$, $p < .001$. In the testosterone group, baseline testosterone levels were not associated with social discounting rate, $r = 0.175$, $p = .374$, nor social distance perception index, $r = -0.154$, $p = .433$. Similarly, baseline androstenedione levels were not associated with social discounting rate, $r = 0.322$, $p = .095$, nor social distance perception index, $r = -0.10$, $p = .614$. In the placebo group, baseline testosterone levels were not associated with social discounting rate, $r = 0.094$, $p = .629$, nor social distance perception index, $r = -0.257$, $p = .178$. Baseline androstenedione levels were not associated with social discounting rate, $r = 0.034$, $p = .863$, but with the social distance perception index, $r = -0.468$, $p = .01$.

AUC measures with average values

we now transform social distances into ranks (i.e. social distance 1 = rank 1, social distance 2 = rank 2, social distance 3 = rank 3, social distance 5 = rank 4, social distance 10 = rank 5, social distance 20 = rank 6, social distance 50 = rank 7, social distance 100 = rank 8), and then calculate AUC. For study 1, testosterone group ($M = 0.60$, $SD = 0.10$) showed significantly smaller AUC than the placebo group ($M = 0.67$, $SD = 0.12$), $t_{56} = -2.42$, $p = 0.019$, 95% CI= [-0.13, -0.01], Cohen's $d = 0.60$. Similarly, in Study 2, testosterone group ($M = 0.61$, $SD = 0.13$) showed significantly smaller AUC than the placebo group ($M = 0.69$, $SD = 0.11$), $t_{114} = -3.76$, $p < .001$, 95% CI= [-0.13, -0.04], Cohen's $d = 0.70$. Thus, the pattern of results was essentially the same with the AUC measures in the main report.

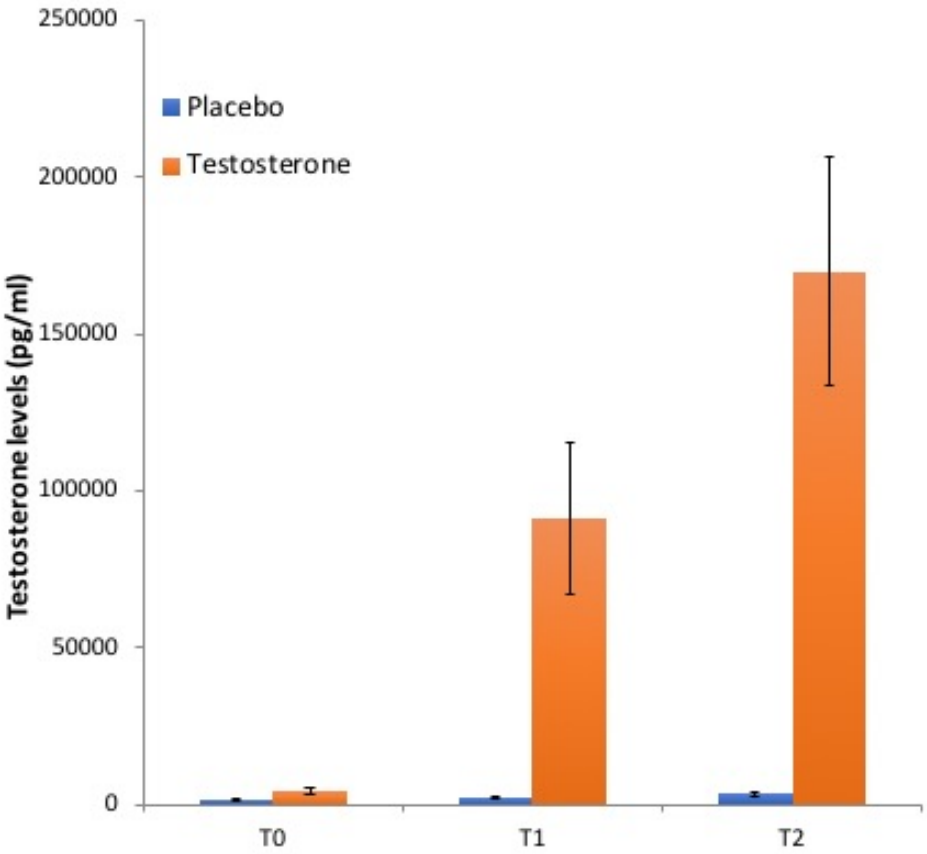

Fig. S1. Salivary testosterone concentrations in the placebo and testosterone group. Testosterone levels increased more in the testosterone than in the placebo group. Mean (± 1 SE) testosterone levels were determined before (T0), 3 h after (T1) and 4 h after (T2) administration.

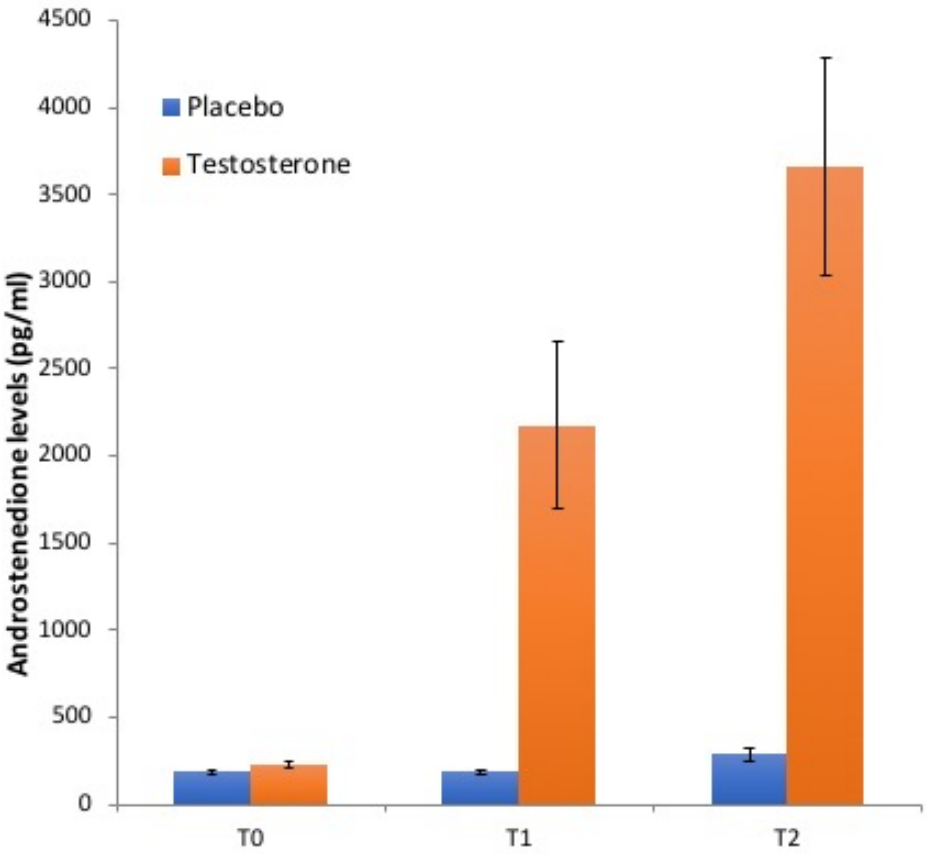

Fig. S2. Salivary androstenedione concentrations in the placebo and testosterone group. Androstenedione levels increased more in the testosterone than in the placebo group. Mean (± 1 SE) androstenedione levels were determined before (T0), 3 h after (T1) and 4 h after (T2) administration.

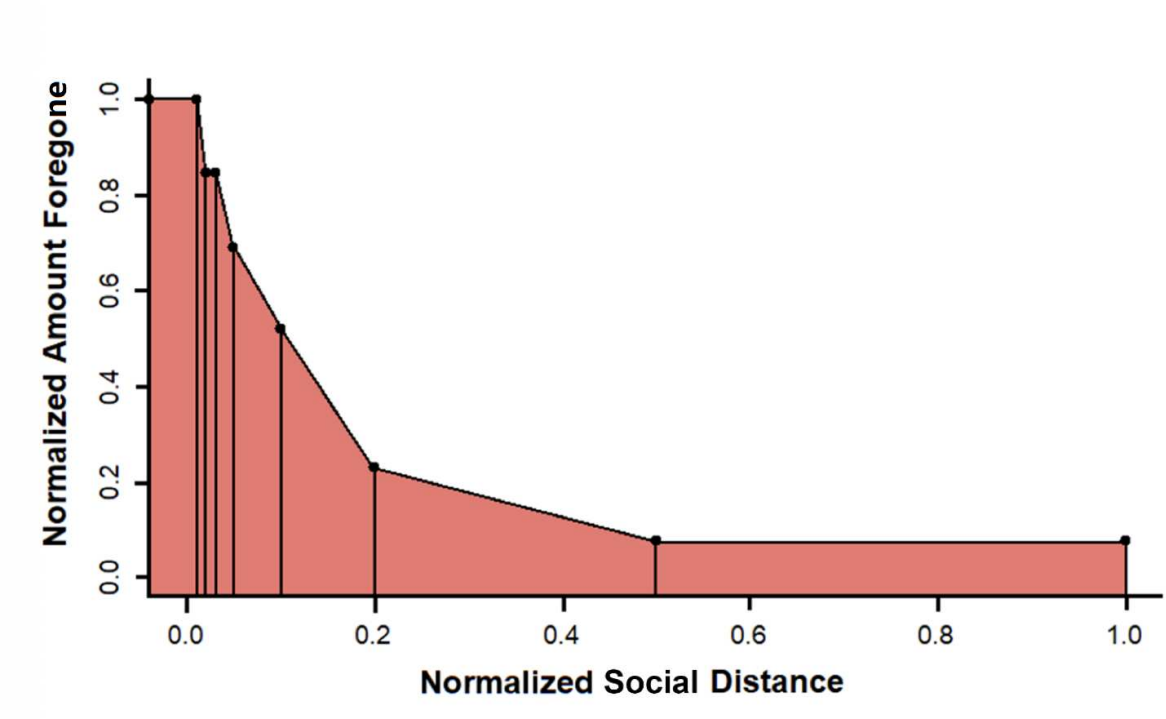

Fig. S3. Calculation of the area under curve (AUC). Data are for Subject 55 in Study 2.

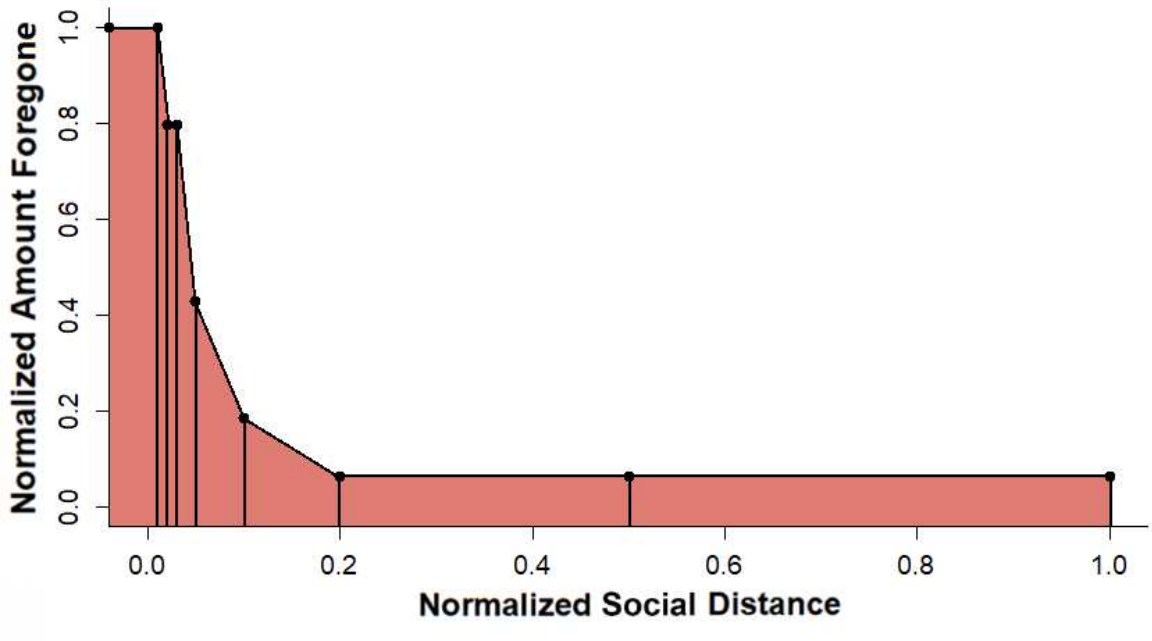

Fig. S4. Calculation of the area under curve (AUC). Data are for Subject 44 in Study 2.

Supplementary References

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